AIN SHAMS UNIVERSITY

FACULTY OF ENGINEERING

Computer Engineering and Systems

Accelerating SAT Solvers through Parallelism

A Thesis submitted in partial fulfillment of the requirements of the degree of

Master of Science in Electrical Engineering

(Computer Engineering and Systems)

by

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Master of Science in Electrical Engineering

(Computer Engineering and Systems)

Faculty of Engineering, Ain Shams University, 2016

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Date: 13 August 2016

Statement

This thesis is submitted as a partial fulfillment of Master of Science in Electrical Engineering, Faculty of Engineering, Ain shams University.

The author carried out the work included in this thesis, and no part of it has been submitted for a degree or a qualification at any other scientific entity.

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Abstract

The Boolean satisfiability (SAT) problem is a very popular problem in computer science. The importance of the problem came from the fact that it is the first problem proven to be NP-complete by Cook in 1971. Nevertheless, SAT solvers are successfully used in several practical applications.

With the advances of multicore processors, parallel SAT solvers have witnessed a significant improvement. Thus, in 2008 a specialized track for parallel SAT solvers was added to the SAT competition. However, the need for optimized sequential SAT solvers is still present and adapting it to cope with the parallel nature is necessary.

In this thesis, we propose a new unorthodox cooperative algorithm for solving satisfiable SAT instances in parallel. We propose a simple yet effective approach that is mainly clause oriented. Our proposed clause oriented algorithm takes full advantage of the parallel nature paradigm.

The most important trait of our algorithm is that it adapts to the parallel temper. This adaptation comes from the fact that our approach scales with the formula clauses since the formula is divided to a number of clauses that are processed in parallel. In addition, our algorithm depends only on an independent metric which is the cardinality of the coverage set of the formula clauses that does not require the sharing of clauses between parallel processing units. This feature provides our algorithm with not only scalability but also saving the communication cost and memory consumption

which is one of the most important challenges in parallelism. Moreover, our proposed approach provides a natural balanced workload distribution.

Unlike other algorithms, our algorithm does not depend on the Boolean constraint propagation problem which is a P-complete problem that is hard to parallelize. Our algorithm is generic and can be implemented on top of any parallel SAT solver as a base solver. This is due to its simplicity and independence of the original algorithm since it only depends on the formula clauses.

We compared our proposed clause oriented algorithm with parallel and sequential SAT solvers through instances from various benchmarks and achieved 15x average speedup.

Thesis Summary

The Boolean Satisfiability problem (SAT) is an NP-complete problem. Besides being a central problem in artificial intelligence, it has significant commercial CAD and test applications, including formal verification, model checking, Automatic Test Pattern Generation (ATPG), Combinational Equivalence Checking (CEC), redundancy removal, and FPGA routing. The acceleration of various computations through the use of parallel computing is an important area of computer science research. Parallel computing techniques are of the most widely used techniques due to their high efficiency, fine granularity, and speedup. Parallel computing is a promising technology for accelerating SAT solvers.

In our thesis, we proposed and implemented a new scalable clause oriented algorithm for solving SAT instances in parallel. Our proposed clause oriented algorithm takes full advantage of the parallel nature paradigm as it adapts to the parallel temper. This adaptation comes from the fact that our approach scales with the formula clauses since the formula is divided to a number of clauses that are processed in parallel.

We compared our proposed clause oriented algorithm with parallel and sequential SAT solvers through instances from various benchmarks and achieved from linear to superlinear speedups.

The thesis is divided into six chapters including lists of contents, tables and figures as well as list of references.

Chapter 1

This chapter gives an introduction to the thesis. It presents the motivation behind the thesis and declares the problem of solving SAT in parallel and the way that we followed to resolve this problem. It also presents the main contributions of the thesis and the organization of this thesis.

Chapter 2

This chapter is a preliminary chapter that reviews the notions and techniques of the Boolean satisfiability problem. It presents a special kind of SAT algorithm which is the DPLL search algorithm and describes its main components. It also describes the CDCL algorithm.

Chapter 3

This chapter introduces the main challenges in parallel SAT solving and holds a comparison between these parallel SAT solvers including their characteristics and the advantages and disadvantages of each one.

Chapter 4

This chapter presents our proposed clause oriented algorithm for solving satisfiable instances in parallel. The chapter describes how our algorithm adapts to the parallel nature paradigm. It shows the main techniques of our algorithm, the algorithm details and architecture. It also clarifies the execution steps through an example and shows the implementation details

Chapter 5

This chapter shows the experimental results in comparison with state-of- the-art SAT solvers through instances from various benchmarks and shows the enhancement in speedup up to superlinear speedup.

Chapter 6

This chapter ends the thesis by conclusions, summary and future work.

Key words: Boolean satisfiability, parallelism

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